STATE OF CALIFORNIA—TRANSPORTATION AGENCY

RONALD REAGAN, Governor

DEPARTMENT OF PUBLIC WORKS

DIVISION OF HIGHWAYS

MATERIALS AND RESEARCH DEPARTMENT

5900 FOLSOM BLVD., SACRAMENTO 95819

November 1969
Final Report
M & R No. 646429

Mr. J. A. Legarra
State Highway Engineer

Dear Sir:

Submitted herewith is a research report titled:

A PRELIMINARY STUDY TO DETERMINE

THE FEASIBILITY OF BUTTON WELDED FUSE PLATES

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Very truly yours,

JOHN L. BEATON
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ACKNOWLEDGEMENTS

The authors wish to express their appreciation to Messrs. R. M. Olson, Co-Director of Highway Sign Research at the Texas Transportation Institute, and Leon Hawkins of the Texas Highway Department for suggesting the "button weld" as a possible solution in the event that torqued bolt-slotted steel fuse plates for break-away steel posts for roadside signs do not perform as reliably as desired.

The authors also wish to express their appreciation to Messrs. R. C. Cassano and J. A. Creed of the Bridge Department of the State of California for their cooperation in reviewing the data received from these tests.

The authors also wish to thank Mr. Leonard Nordmann, welder for the Materials and Research Department for his expeditious manner of preparing (1) sample test jigs, (2) sample button welds, and (3) button welded fuse plates for testing and evaluation.

This is the final report for "Button Welded Fuse Plates". The work was done under the 1968-69 Work Program Authorization 646429. All work was conducted at the Materials and Research Department, 5900 Folsom Blvd., Sacramento, California.

ABSTRACT

REFERENCE: Nordlin, E. F., Jonas, P. G., and Scharosch, D. L., "A Preliminary Study to Determine the Feasibility of Button Welded Fuse Plates", State of California, Department of Public Works, Division of Highways, Materials and Research Department. Research Report No. 646429, November 1969.

ABSTRACT: Button welds in steel plates are investigated to determine if they can be consistently produced to provide shear failure at a predetermined level. The results of this preliminary study indicate that button welded steel fuse plates are feasible as a more reliable alternate to the torqued bolt-slotted steel fuse plate currently used in breakaway steel posts for roadside signs. However, further investigation, including dynamic tests, will be necessary to establish the exact plate thickness and button weld size necessary to provide a button welded fuse plate with the dynamic shear failure behavior required in the fuse plate of a breakaway steel post during impact by a colliding vehicle.

KEY WORDS: Breakaway supports, welding, welded joints, testing, sign structures, shear strength.

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I. INTRODUCTION

For nearly two years it has been the policy of the California Division of Highways to mount all ground mounted roadside signs on posts that breakaway with a minimum of resistance from impact by a colliding vehicle. Steel posts are made breakaway by incorporating design features proposed by the Texas Highway Department and developed by the Texas Transportation Institute in a cooperative research project sponsored by the state highway departments of various states including California.

The principle features of this breakaway steel post design are a slip base and a fuse plate or weakened hinged plane in the post immediately below the mounted sign which permits the impacted post to swing up and away from the colliding vehicle. The fuse plate must be designed to carry the stresses induced by wind loadings on the sign but to fail under the higher impact loads imposed in a vehicle collision.

The T.T.I. (Texas Transportation Institute) developed fuse plate adopted by the California Division of Highways utilizes a slotted plate which is restrained from slipping by the clamping action of two torqued high strength bolts. The strength of this fuse plate is dependent to a high degree upon the amount of torque in the high strength bolts. Problems can develop in seeing that the desired tension is placed and maintained in the bolts. California Division of Highways' Standard Plan S43-9 dated December 4, 1968 (see Figure 1 of this report), shows the details for current breakaway sign posts and prescribes that the bolts shall be tightened to torques that are specified. Other states specify that the bolts shall be tightened by the "turn of the nut" method.

To date, the reported experience of the California Division of Highways with the torqued bolt-slotted steel fuse plate in breakaway steel posts for signs has been satisfactory. However, there is concern that problems have reportedly developed in at least one other state and could develop in California involving unsatisfactory fuse plate action caused by difficulties encountered in controlling the correct load on the bolts to insure satisfactory action.

In a meeting in California in December 1967, Dr. Robert Olson, co-director of the highway sign research conducted at T.T.I., and Mr. Leon Hawkins, of the Texas Highway Department, suggested to members of the California Division of Highways that button welds might be employed to insure a more reliable and predictable fuse plate load capacity. In a button welded steel fuse plate, the load capacity would be dependent on the shearing strength of button welds used to fasten two overlapping plates together. We felt that the idea had merit but realized that further investigation would be necessary.

Therefore, on February 2, 1968, Research Project No. M & R 646429, financed with state funds, was initiated as a preliminary study to determine the feasibility of button welded steel fuse plates for use on breakaway steel posts for ground mounted highway signs. The study was to determine if button welds could be produced on a production line basis which will accurately and consistently fail at a predetermined shear strength. The ultimate promise of the button weld lies in the potential that preset cycling of automatic welding machines will produce welds completely divorced from the direct control of the operator.

II. CONCLUSIONS

It appears that the following conclusions can be reached from this preliminary study:

1. Button welds can be consistently prepared to meet a variety of predetermined shear strength levels.

2. Button welded steel fuse plates are feasible for reliable use on breakaway steel posts for ground mounted roadside signs. However, further study, including dynamic testing, will be necessary to establish the exact plate thickness and button weld size necessary to provide a button welded fuse plate with the same dynamic behavior exhibited by the current torqued bolt-slotted steel fuse plate in a breakaway steel post during impact by a colliding vehicle.

III. INFORMATION

The button weld is looked on as an attractive, possible alternate method of controlling fuse plate strengths because (1) they lend themselves to mass production, (2) they require no maintenance, (3) they can be replaced with ease, and (4) they are contended to have predictable shear strengths. It is with this last point that this project was initiated, e.g., to determine whether or not button welds could be produced consistently with predictable shearing strengths.

The button weld sizes in this study were selected to represent the strength of the current slotted steel fuse plate connection fastened by torqued bolts.

In an effort to meet the objectives, this project was organized into five phases. A group of test samples were prepared for each phase. The results or conclusions obtained from one group of samples was necessary prior to advancing to the next group. The order of the button weld investigation progressed as follows:

Test Group 1. Evaluating the welding machine variables.

Test Group 2. Testing the current torqued bolt-slotted fuse plates to determine their shear strengths.

Test Group 3. Preparing preliminary button weld shear tests.

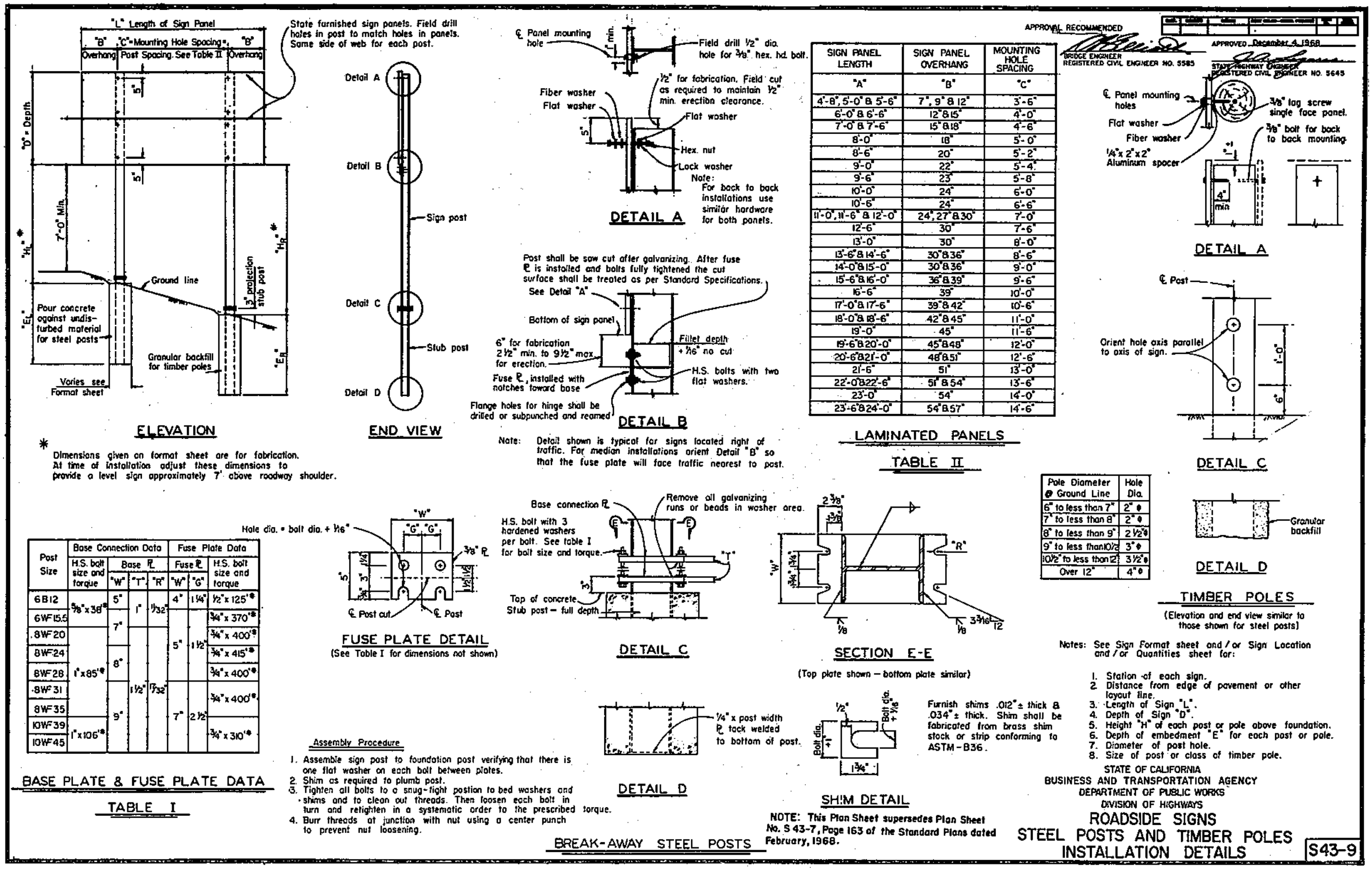
Test Group 4. Testing full size button welded fuse plates containing strengths comparable to the current torqued bolt-slotted fuse plate connection.

Test Group 5. Testing full size button welded fuse plates at controllable machine settings.

All button welds were made with a Linde Sigmatic welding control, Type SCC-8, in conjunction with a Linde power supply, Type SVI-1000, and a Type ST-5 in-line welding torch with a #16 head.

The fuse plate connection tested conformed in geometry to the "Fuse Plate Detail" shown on California Division of Highways' Standard Plan S43-9 titled "Roadside Signs, Steel Posts and Timber Poles Installation Details" dated December 4, 1968. The particular fuse plate size used in this project for testing and evaluation was selected to conform with the requirements of the size 6B12 steel post (see Figure 1).

The plate thicknesses were reduced from 3/8 inch to 1/4 inch as an initial engineering decision. The button welds that join the two plates are still representing the weaker link even with the reduced plate thicknesses. Plate thickness is accepted as a significant variable in the controlling of button weld soundness. The scope of this project was not to determine to what extent plate thickness affects button welding, consequently throughout this project fuse plate thickness was held constant at 1/4 inch.



*** Dimensions given on format sheet are for fabrication. At time of installation adjust these dimensions to provide a level sign approximately 7' above roadway shoulder.**

Post Size	Base Connection Data: H.S. bolt size and torque	Base ℄ "W"	Base ℄ "T"	Base ℄ "R"	Fuse Plate Data: Fuse ℄ "W"	Fuse ℄ "G"	H.S. bolt size and torque
6B12	5/8"x38'*	5"	1"	11/32"	4"	1 1/4"	1/2"x125'*
6WF15.5		7"			5"	1 1/2"	3/4"x370'*
8WF20	1"x85'*		1 1/2"	17/32"			3/4"x400'*
8WF24		8"					3/4"x415'*
8WF28							3/4"x400'*
8WF31		9"			7"	2 1/2"	3/4"x400'*
8WF35							
10WF39	1"x106'*						3/4"x310'*
10WF45							

BASE PLATE & FUSE PLATE DATA

TABLE I

SIGN PANEL LENGTH "A"	SIGN PANEL OVERHANG "B"	MOUNTING HOLE SPACING "C"
4'-8", 5'-0" & 5'-6"	7", 9" & 12"	3'-6"
6'-0" & 6'-6"	12" & 15"	4'-0"
7'-0" & 7'-6"	15" & 18"	4'-6"
8'-0"	18"	5'-0"
8'-6"	20"	5'-2"
9'-0"	22"	5'-4"
9'-6"	23"	5'-8"
10'-0"	24"	6'-0"
10'-6"	24"	6'-6"
11'-0", 11'-6" & 12'-0"	24", 27" & 30"	7'-0"
12'-6"	30"	7'-6"
13'-0"	30"	8'-0"
13'-6" & 14'-6"	30" & 36"	8'-6"
14'-0" & 15'-0"	30" & 36"	9'-0"
15'-6" & 16'-0"	36" & 39"	9'-6"
16'-6"	39"	10'-0"
17'-0" & 17'-6"	39" & 42"	10'-6"
18'-0" & 18'-6"	42" & 45"	11'-0"
19'-0"	45"	11'-6"
19'-6" & 20'-0"	45" & 48"	12'-0"
20'-6" & 21'-0"	48" & 51"	12'-6"
21'-6"	51"	13'-0"
22'-0" & 22'-6"	51" & 54"	13'-6"
23'-0"	54"	14'-0"
23'-6" & 24'-0"	54" & 57"	14'-6"

LAMINATED PANELS

TABLE II

Pole Diameter @ Ground Line	Hole Dia.
6" to less than 7"	2" ⌀
7" to less than 8"	2" ⌀
8" to less than 9"	2 1/2" ⌀
9" to less than 10 1/2"	3" ⌀
10 1/2" to less than 12"	3 1/2" ⌀
Over 12"	4" ⌀

Assembly Procedure

1. Assemble sign post to foundation post verifying that there is one flat washer on each bolt between plates.
2. Shim as required to plumb post.
3. Tighten all bolts to a snug-tight postion to bed washers and shims and to clean out threads. Then loosen each bolt in turn and retighten in a systematic order to the prescribed torque.
4. Burr threads at junction with nut using a center punch to prevent nut loosening.

NOTE: This Plan Sheet supersedes Plan Sheet No. S 43-7, Page 163 of the Standard Plans dated February, 1968.

Notes: See Sign Format sheet and / or Sign Location and / or Quantities sheet for:

1. Station of each sign.
2. Distance from edge of pavement or other layout line.
3. Length of Sign "L".
4. Depth of Sign "D".
5. Height "H" of each post or pole above foundation.
6. Depth of embedment "E" for each post or pole.
7. Diameter of post hole.
8. Size of post or class of timber pole.

STATE OF CALIFORNIA
BUSINESS AND TRANSPORTATION AGENCY
DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS

ROADSIDE SIGNS
STEEL POSTS AND TIMBER POLES
INSTALLATION DETAILS

S43-9

FIGURE 1

ROADSIDE SIGN INSTALLATION DETAIL

IV. TEST PROCEDURE

Test Group 1

In this first phase of the investigation, twenty three test samples were prepared by operating the button welding (MIG spot welding) machine fusing two 1/4 inch cold rolled 1-1/4 inch wide steel straps together (see Figure 2). These samples were designated as Test Group 1. The grade of steel in these straps and in all of the fuse plates in this study was AISI 1018 with a carbon content of 0.15 to 0.20 percent. The button weld specimens of Test Group 1 were prepared for analysis to determine the significant machine

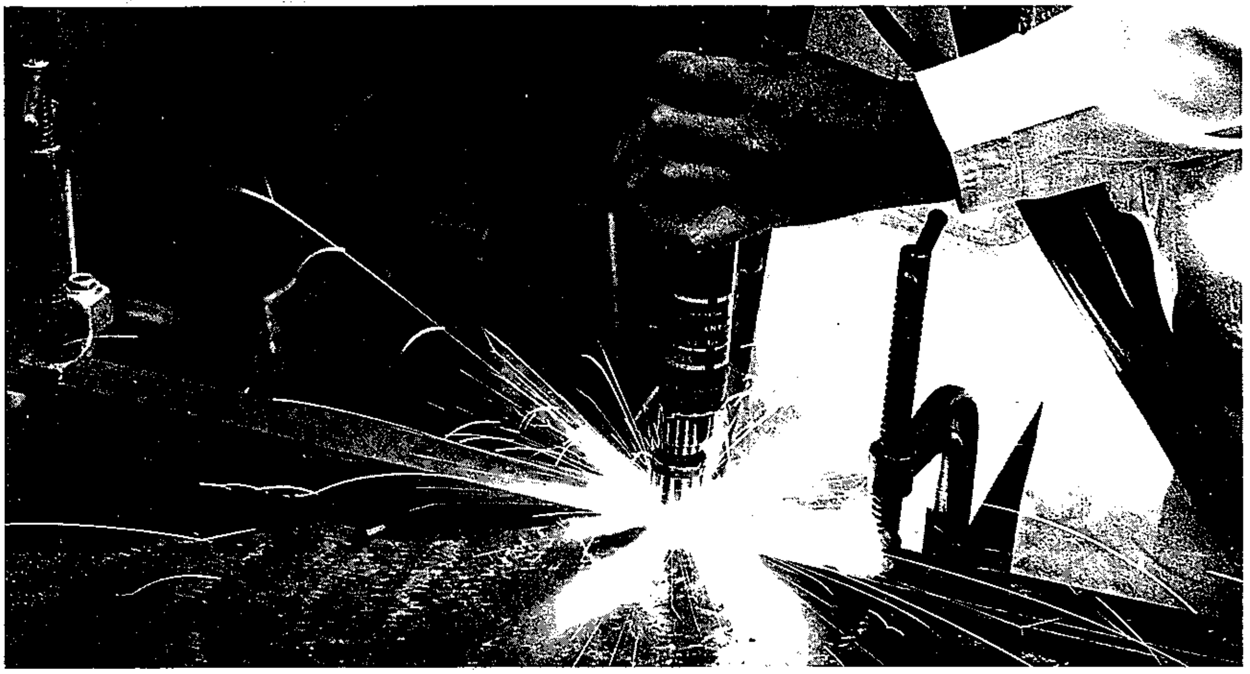


FIGURE 2

BUTTON WELDING

parameters that affect the nugget size, penetration profile and other geometrical and fusion factors that influence the ultimate shear strength of button welds. The machine variables investigated were:

1. Slope.

2. Inductance.

3. Wire amount (cycle duration control).

4. Button welding current.

5. Button welding voltage.

The machine variables held constant throughout all tests were:

1. Wire speed.

2. Wire size*.

3. CO_2 gas shielding flow rate at 40 CFH.

The specific machine settings used in welding each of the test samples are summarized in Appendix C, Table II.

All button weld samples were prepared in the flat position and on a steel, well grounded table. The first fifteen button weld samples were generated on the two 1/4 inch steel straps with the top strap containing a 1/8 inch diameter pilot hole. These samples were numerically identified 1 through 15. Eight subsequent weld samples were generated on straps with the pilot hole increased to 1/4 inch diameter. These button weld samples were numerically identified 1A through 8A. Each button weld specimen was steel stamped for identification, cut in half, polished, and etched for macrophotography (see Appendix A).

No physical tests were performed on any of the Test Group 1 samples. The primary purpose of these samples was to study the affect of the various welding machine variables on the button weld size and profile.

Test Group 2

For the second phase of this study, five identical samples of slotted steel fuse plates fastened with high strength bolts were prepared in conformance with the details shown in Figure 1 for a 6B12 post size except the thickness of the plate was 1/4 inch. The 1/2 inch diameter high strength bolts were torqued by a calibrated torque wrench to the specified 125 foot-pounds. These five bolted samples, known as Test Group 2, were tested to determine their ultimate shear strength under static load. The results of these physical tests are summarized in Appendix D, Table VI. The conclusions arrived at from this group were (1) the Mean static shearing strength, (2) the Standard Deviation, and (3) the Coefficient of Variation for the five tests of the current torqued bolt-slotted fuse plate connection.

The Test Group 2 information was necessary to establish the ultimate shear strength to be developed in the button welded fuse plate.

* 1/16 inch diameter Linde 65, Bare Mild Steel Electrode for Gas Metal-Arc Welding, AWS-ASTM Classification E60S-2.

Test Group 3

As the next phase of this study, simple shear specimens containing two button welds were prepared for physical testing and evaluation. The intent of this group of samples, Test Group 3, was to determine (1) button weld shear strength as a function of button weld size and (2) whether button welds can be prepared consecutively and uniformly. Eighteen specimens were prepared for physical testing to determine the performance of various button weld sizes (see Figure 3). Six different machine settings were used with three test

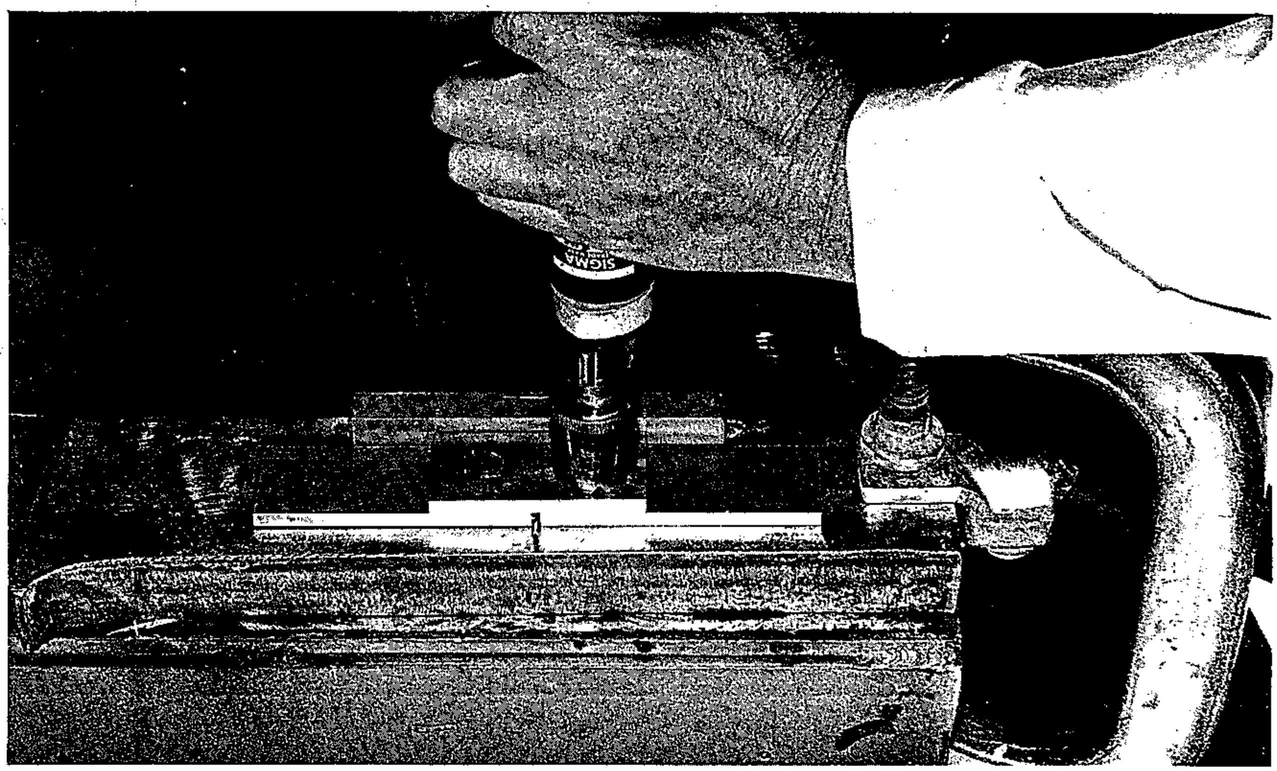


FIGURE 3

SIMPLE SHEAR SPECIMEN

specimens prepared for each setting as summarized in Appendix C, Table III. The sequence for preparing each set of three shear test specimens were:

1. Obtain the desired welding machine control settings.

2. Generate a single sample button weld (Button Weld 1B is an example).

3. Generate three shear test specimens, each with two welds (Button Welds 2B and 3B are examples).

4. Generate a single final sample button weld (Button Weld 8B is an example).

The sample button welds prepared before and after each set of three shear test specimens are basic to any controlled testing analysis. If, for example, the strength of each three specimens varied greatly, it would be expected to detect a significant difference in the two sample button welds when cut in half, polished, and etched. If on the other hand each three test specimens show a degree of uniformity as to shearing strength, the two sample button welds depict precisely the nugget geometry of the test specimens which they represent. Macrophotographs of the initial and final sample button weld for each of the six sets of shear test specimens are shown in Appendix A. The six sets of shear specimens were prepared in this fashion and physically tested in shear to failure under static load. The results of these shear tests are summarized in Appendix D, Table VII.

The conclusions drawn from the results of Test Group 3 were (1) the ultimate shearing strength as a function of button weld size and (2) the degree of consistency between consecutive button welds at fixed welding machine settings.

With the average ultimate static shearing strength of the torqued bolt-slotted fuse plate connection known from Test Group 2 and the button weld ultimate static shearing strengths available from Test Group 3, sufficient information was now available to prepare full size button welded fuse plates.

Test Group 4

Test Group 4 consisted of eleven full size button welded fuse plate specimens. These specimens were all prepared from 1/4 inch cold rolled steel material with 1/4 inch diameter button weld pilot holes (see Figure 4). The button welds for these fuse plate specimens were all generated at the same welding machine control setting; namely, the control setting from Test Group 3 that produced a fuse plate static shear strength comparable to the torqued bolt-slotted fuse plate. The machine setting from these specimens is shown in Appendix C, Table IV.

Ten of the eleven specimens were physically tested to failure in shear. The test results are summarized in Appendix D, Table VIII. The eleventh specimen was not tested. It was retained for demonstration purposes. Figure 5 shows the three point loading fixture for testing the full size button welded fuse plate specimens. This testing fixture was so designed, dimensionally, as to result in a machine load reading equal to the induced shearing load on the specimen.

As will be discussed further under Data Analysis, the results of Test Group 4 were not as consistent as would be desirable, even though the Coefficient of Variation of the button welded fuse plates of Test Group 4 was slightly improved when compared to the Coefficient of Variation for the torque bolt-slotted fuse plate tests of Test Group 2.

The variation observed in the button welded fuse plates of Test Group 4 was attributed to operating the welding machine at a low value cycle duration control setting.

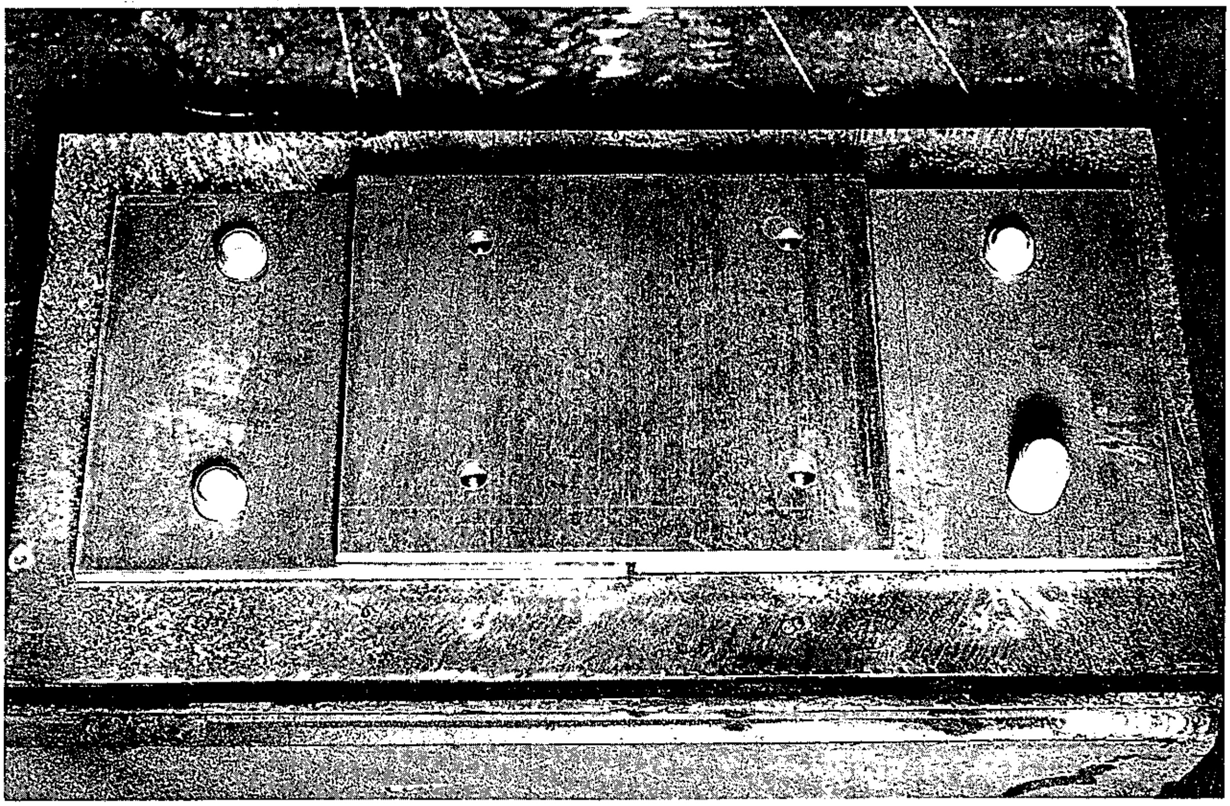


FIGURE 4

FUSE PLATE BUTTON WELDING JIG

From the button welding performed for Test Group 1 and the subsequent button welding for Test Group 3, it was observed that increased (or longer) cycle durations contribute significantly to button weld consistency. Operating with a very short cycle duration, as was the case with the small button welds selected for the fuse plate connections of Test Group 4, appeared to produce variable results which could be improved by increasing the cycle duration. This led to Test Group 5.

Test Group 5

Test Group 5 consisted of another eleven full size button welded fuse plate specimens. These plates were identical in all respects to those of Test Group 4 except for the button weld size (see Figure 6). The button weld size (which was found to be a function of cycle duration) was increased slightly to a point that it was believed the

FIGURE 5

TESTING MACHINE IN OPERATION

welding machine would operate more consistently. The machine settings for the button welds of Test Group 5 are shown in Appendix C, Table V. Ten button welded fuse plates were physically tested in shear to failure. The data recorded on this group as with all previous shear tests was the ultimate shearing load. The results of the shear tests are summarized in Appendix D, Table IX.

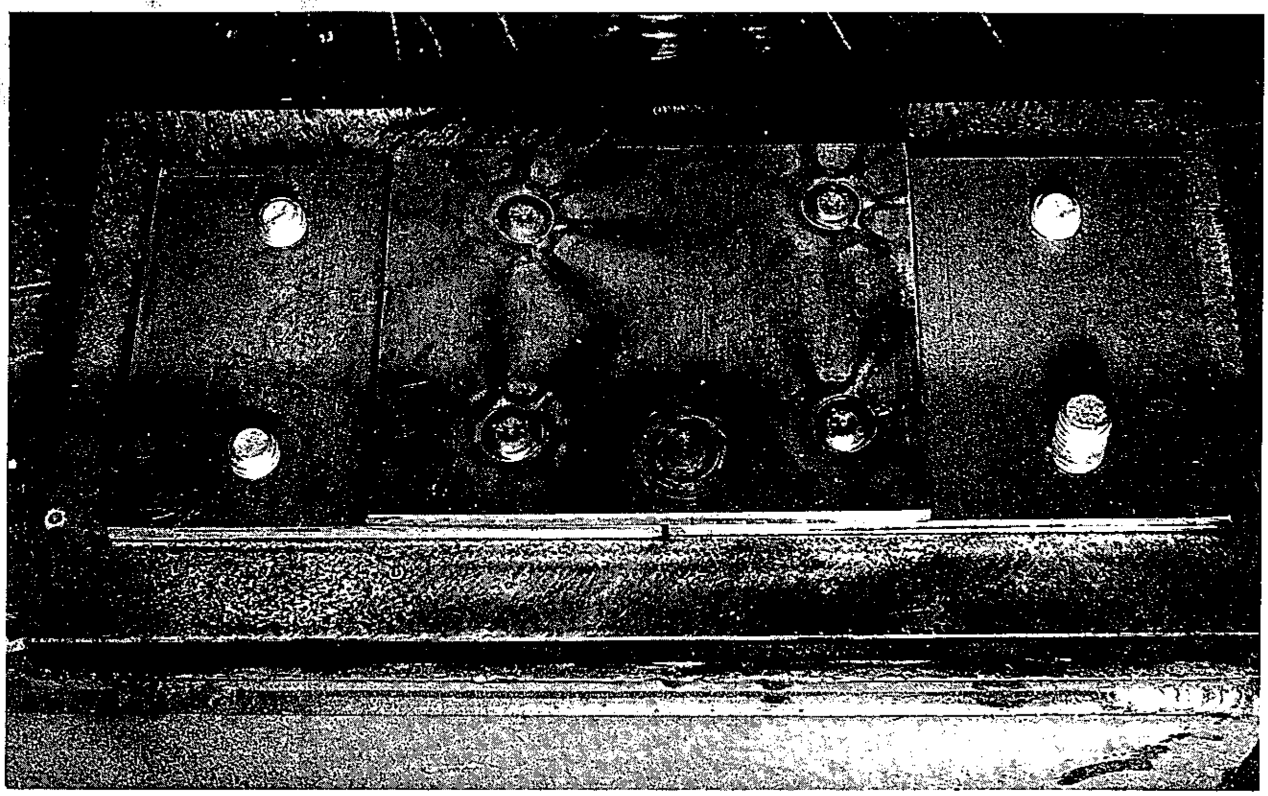


FIGURE 6

BUTTON WELDED FUSE PLATE

As was anticipated from the welding machine's performance on earlier button welds, the consistency of fuse plate strengths, with slightly increased cycle duration, was greatly improved. Test Group 5 concluded the physical testing phase of this project.

VI. DATA ANALYSIS

Test Group 1

The analysis of data for this project began by reviewing the macrophotographs of button weld specimens (see Appendix A) of Test Group 1. The first series of button welds, of which there were 15, were prepared to determine the welding machine parameters that significantly affect penetration control of the button weld process. These first weld specimens were prepared on 1/4 inch steel plates with the top plate containing a 1/8 inch diameter pilot hole.

Macrophotographs #1 through #4, shown in Appendix A along with other macrophotographs, depict nugget geometry while varying only the welding machine cycle duration control. Appendix B contains the welding machine cycle duration control calibration curve that describes the amount of wire in inches fed to a button weld puddle versus the cycle duration control setting of the welding machine.

All of the other machine controls were held constant at nominal values. Appendix C, Table II, contains the data of the precise welding machine control settings for the samples prepared for Test Group 1. The conclusions that were drawn from the first four button welds were:

1. Weld nugget penetration is not significantly affected by the welding cycle duration control until substantial changes have been made.

2. Weld nugget profile throughout the penetration portion is constantly varying.

Macrophotograph #5 depicts the effect of varying the slope control. The machine cycle duration control was returned to the setting used in the preparation of button weld #1 and the slope control was changed from flat to steep maintaining the percentage of slope. The conclusion drawn from weld #5 was that changing the slope from flat to steep hinders button weld fusion. The macrophotograph of weld #5 shows no penetration even though the 1/8 inch diameter pilot hole was removed in sectioning.

The welding machine slope control was then returned to the flat position (at the original position prior to weld #5).

Macrophotograph #6 depicts the effect of varying the inductance control. Again the welding machine was maintained at the control setting similar to weld #1 except the inductance control was changed from low to high maintaining the same percentage of inductance. The conclusion drawn from weld #6 was that changing the inductance from low to high hindered button welding. The macrophotograph of weld #6 shows no fusion.

Since the conclusions drawn to this point in testing, e.g., (1) increasing the slope control from flat to steep actually hindered button welding and (2) increasing the inductance control from low to high also hindered button welding, it was decided to maintain the slope control setting in the flat position and maintain the inductance control in the low position but minimize the percentage of inductance.

Macrophotograph #7 depicts the effects of button welding with the inductance control maintained in the low position with the degree of inductance control reduced to the minimum value. The conclusion drawn from weld #7 was that minimum inductance reestablishes and improves the penetration and sound of the welding operation. Prior to weld #7, the operation sounded as though welding was occurring sporadically based on the popping sounds and the surging of sparks from the welding torch nozzle vents.

Macrophotograph #8 depicts the effects on the button welding with the inductance control maintained in the low position with the degree of inductance control at the minimum value and maintaining the slope control in the flat position but with the degree of slope control now also reduced to the minimum value. The conclusion drawn from weld #8 was that minimum inductance and minimum slope significantly improves the sound and fusion in the button welding operation. During the welding cycle the welding was extremely stable sounding (buzzing type sound).

Macrophotographs #8 through #15 depict the effects on nugget geometry (penetration and nugget size) resulting from varying the welding duration control. All other machine controls were maintained constant. The conclusions drawn from welds #8 through #15 were:

1. Welding duration control significantly affects the amount of penetration of the button weld.

2. The lower limit for the welding duration control causes unstable nonpenetrating button welds.

This concluded the first part of Test Group 1 which maintained the pilot hole constant at 1/8 inch diameter.

The second part of Test Group 1 consisted of eight button welded samples with a new pilot hole size of 1/4 inch diameter.

Macrophotographs #1A and #2A depict the effects of a short cycle or short welding machine duration setting on button welding with 1/4 inch diameter pilot holes. Button welds #1A and #2A were prepared with a welding machine cycle duration control setting to consume 3.3 inches of wire for each button weld. The welding duration control was then increased 1.3 inches per cycle to 4.6 inches per cycle at which point welds #3A and #4A were prepared. Macrophotographs #3A and #4A depict the results of increasing the welding duration control while maintaining all other machine controls constant. Macrophotographs #5A and #6A depict the results of increasing again the weld duration 0.8 inches per cycle to 5.4 inches of wire per cycle. A significant increase in penetration is evident from the macrophotographs at this setting. Macrophotographs #7A and #8A show no detectable increase in penetration but do show the establishing of the button weld head. Welds #7A and #8A were prepared with an increased weld duration control of 0.8 inches of wire per cycle to a total wire deposit of 6.2 inches per cycle.

The conclusions drawn from welds #1A through #8A were:

1. Increasing the pilot hole to 1/4 inch diameter reestablished penetration for short duration button welding (small button welds).

2. Short cycle duration control settings produce an erratic button welding condition. The system was on occasion noted to cycle twice on the command for one cycle sequence (weld #4A).

3. Button welds can be prepared with penetration and with flush button heads.

4. Button weld profile is spiked indicating a desirable fusion condition which becomes longer or shorter for minor changes in the cycle duration control.

This concludes analysis of the data from Test Group 1 which dealt with the preliminary evaluation of the welding machine parameters which affect basic button weld nugget size and penetration profile.

The significant conclusions arrived at from macrophotographic analysis of Test Group 1 weld specimens (see Appendix A, Table I) are:

1. Operating the welding machine at minimum control settings, e.g., slope in flat position and inductance in the low position enhances a controlled button welding operation.

2. A 1/4 inch diameter pilot hole improves controlled penetration at the lower cycle duration settings.

3. The cycle duration control setting determines both the button weld penetration and button weld shear area when holding all other welding machine parameters constant at nominal values.

<u>Test Group 2</u>

Test Group 2 consisted of shear tests on five full size specimens of torqued bolt-slotted steel fuse plate connections. Each specimen involved torquing the two bolts to 125 foot-pounds. The primary intent of these tests was to determine the approximate total static shear strength of the current torqued bolt-slotted fuse plate design. The current fuse plate design fails at a desired shear load when the frictional force between two plates, induced by the clamping force from two torqued high strength bolts, is overcome and the one plate with slotted holes is permitted to slip away from the other plate. In this study it was proposed that shear failure at this same load level can be achieved by fastening the two plates together with two carefully controlled button welds. It is also proposed as part of this project, and must be substantiated, that the predictability of the shearing strength of the button welded fuse plate design will be substantially better than that of the present torqued bolt method.

The five test specimens were assembled in three sets with a different person torquing the bolts in each set. This resulted in one person torquing specimens #1 and #2, a second person torquing specimens #3 and #4, and a third person torquing specimen #5. Specimens #1 through #4 were torqued without any lubrication on the bolt threads. Specimen #5 had the bolt threads lubricated with molybdenum disulfide.

The five shear tests of the bolted connection were conducted to determine, in each case, the ultimate shear strength. The data was then analyzed for:

1. Mean static ultimate shear strength.

2. Standard Deviation.

3. Coefficient of Variation.

Appendix D, Table VI, contains the results of these shear tests. This concluded the analysis of Test Group 2.

Test Group 3

Test Group 3 specimens were the first to include physical testing of button welds in shear. These tests were performed on simple shear specimens to determine the ultimate shear strength of various single button welds. The size of the button was controlled completely by the wire duration control of the welding machine. Six different sets of three identically prepared specimens (two welds each) were prepared and tested. Each set had its respective two control button welds, one initial and one final sample weld.

The first set of test specimens contained the minimum size button weld which can be prepared on two 1/4 inch plates containing the desired parallel nugget profile without losing fusion with the second (or bottom) 1/4 inch plate. Machine setting information for the six button welds in this first set of three specimens (welds #2B through #7B) and for the two control button welds for this first set (welds #1B and #8B) are shown in Appendix C, Table III, which also summarizes the data for all specimens in Test Group 3.

The macrophotographs of the control button welds for this first set of specimens are identified as #1B and #8B (see Appendix A). Notice from these macrophotographs the limited penetration of the button weld.

The sample shear specimens of Test Group 3 were aligned in a small fixture as shown in Figure 3. The button welding torch was held perpendicular to the work with the filler wire clipped back (recessed) slightly enabling a running start. A good ground connection was found to be very important.

The remaining five sets of button weld shear specimens were prepared at convenient machine control settings to incorporate the entire range of button weld sizes that develop satisfactory top plate to bottom plate penetration. The machine cycle duration control, again, was the only parameter varied during the fabrication of samples for Test Group 3, and it was varied only when a new size button weld was desired. The data representing the static ultimate shear strength of each set of button welds of Test Group 3 are found in Appendix D, Table VII. With the completion of Test Group 3, a graph was prepared to demonstrate the button weld shear strength as a function of cycle duration control (see Figure 7).

Conclusions resulting from the analysis of data derived from Test Group 3 are:

1. Button weld static shear strength can be controlled.

2. The range of button weld shear strengths will enable full scale button welded fuse plate fabrication (Test Group 4) to begin immediately. Macrophotographs of the control buttons for Test Group 3 depict very clearly that the duration of the cycle is directly related to the size of the penetrating button weld cross section at the interface of the two plates. This is the area in shear when the samples are tested.

Test Group 4

Test Group 4 includes eleven full size fuse plates, each containing four button welds (two on top and two on the bottom). The button welds in this test group were selected to provide the same fuse plate static shear strength as the torqued bolt-slotted fuse plates tested in Test Group 2. The machine settings for the button welds in all of the test specimens in this group were identical and shown in Appendix C, Table IV. Ten of the eleven specimens were tested for ultimate shear strength, the eleventh as mentioned earlier was retained for demonstration. After the ten were tested for ultimate shear strength, the data were analyzed for Mean, Standard Deviation, and Coefficient of Variation (see Appendix D, Table VIII).

Comparing the Test Group 4 button weld fuse plate connection performance with that of the Test Group 2 torqued bolt-slotted fuse plate connection, we find the following:

1. The ultimate static shear strength of the proposed button welded connection has a 12 percent higher strength than the current bolted connection.

2. The reproducibility of button welded shear plate connections exceed that for the bolted connection.

3. The button weld selected to simulate the torqued bolt-slotted fuse plate strength was the smallest button weld investigated with this machine, without losing button weld penetration.

With the requirement of having two button welds controlling the shear strength of the fuse plate, it was necessary to select the smallest button weld which had been investigated in Test Group 3. This size button weld is the smallest size attainable by the machine (with the control setting and plate thickness restrictions) before

BUTTON WELD SHEAR TEST

LINDE SIGMATIC CONTROL @ 600 AMPERES, 38 VOLTS

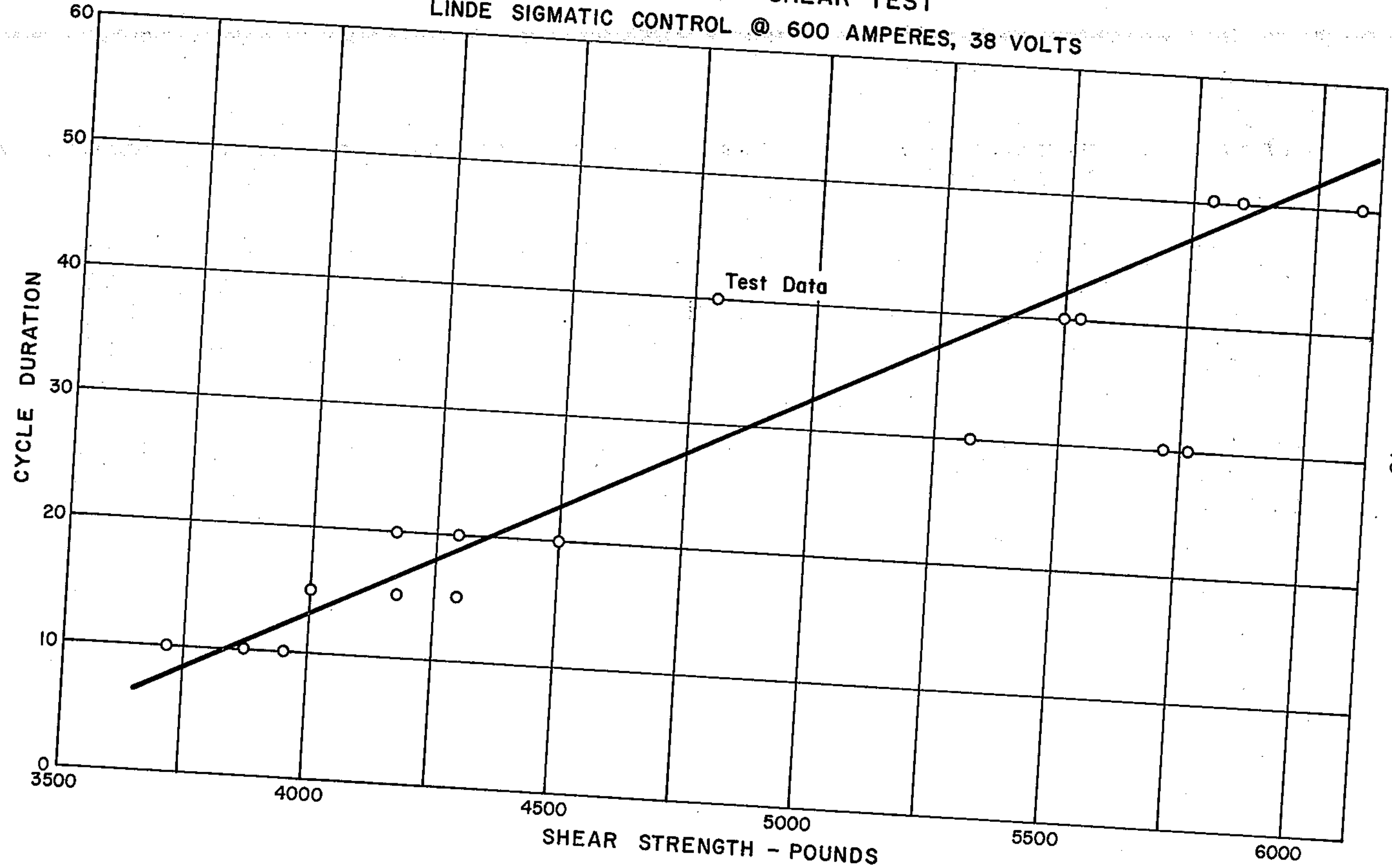


FIGURE 7

fusion is lost between the two plates. At these machine control settings for wire speed and wire cycle duration, the fairly wide variations in button weld strength which results in Test Group 4 are not surprising. The welding machine cycle duration control for preparing the specimens of Test Group 4 was set at 10/360 x 100% = 2.8% of its over-all operating range.

Test Group 5

Test Group 5 specimens were similar to the Test Group 4 specimens except for the size of the button weld selected. Because the welding machine operating performance for Test Group 4 test specimens was felt to be hindered by the restriction of the small button weld, the cycle duration control was increased for the Test Group 5 specimens into the range of the control where button weld performance was believed would be more consistent. It was recognized at the onset that this would, at the same time, increase the over-all shear strength of the fuse plate.

Eleven full size fuse plate connections were then prepared. As with Test Group 4, each plate contained one button weld in each of the four corners of the fuse plate connection. Ten specimens were tested for the ultimate shearing strength. The ultimate shearing strengths of the ten specimens were than analyzed for Mean, Standard Deviation, and Coefficient of Variation (see Appendix D, Table IX).

The improvement can be seen from the Coefficient of Variation of Test Group 5. The increased fuse plate strength was anticipated. This concludes the data analysis of Test Group 5 and of this project.

VI. TEST EVALUATION

Based on the button welds prepared and tested for this preliminary study, it inconclusively appears that there is an optimum plate thickness to button weld size combination that would enable a specific ultimate shear strength to be achieved with consistency in a button welded fuse plate. We have shown that the degree of button weld shear strength consistency is increased at longer cycle duration control settings. This leads us to the condition which occurred between Test Groups 4 and 5 where the consistency improved but the static shear strength of the button welded connection increased beyond the desirable range established by the tests on the current torqued bolt-slotted steel fuse plate. Although testing is not continued in this study, it is believed that comparable static shear strengths with a high degree of consistency could be obtained in button welded fuse plates if:

1. The steel plate thicknesses were reduced.

2. The wire size reduced.

3. The pilot hole diameter reduced.

Test Group 4 button welded fuse plate specimens showed only slightly higher average shear strengths than the Test Group 2 torqued bolt-slotted fuse plates. Furthermore, even though the shear strengths varied, the Test Group 4 button welded plates appear to be a more reliable shear connection than the current torqued bolt-slotted fuse plate design.

In this preliminary study, the two basic fuse plate designs have been compared on the basis of their shear strength under static load. It is realized that a button welded fuse plate design should also be dynamically tested before it would be adopted for use in a breakaway sign post. However, this preliminary study involving static load shear strengths show that any of the desired properties of a torqued bolt-slotted fuse plate can be consistently produced in a button welded fuse plate.

Any future dynamic tests should be aimed at determining a button weld that when incorporated into a fuse plate connection results in the same energy absorption at failure as does the torqued bolt-slotted fuse plate. The variation in failure energy would be the primary point of concern.

At this time we have received no information to indicate that the torqued bolt-slotted fuse plates are not performing satisfactorily in breakaway steel posts for signs erected by the California Division of Highways. Other highway departments have reported problems such as fuse plates shearing under wind loads on the sign or fuse plates not shearing when the sign post is struck by a vehicle. Some of the states tighten the high strength bolts in the fuse plate by the "turn of the nut" method whereas California has required the bolts to be torqued to a specific value using a calibrated torque wrench. This may be the reason for the good performance of the torqued bolt-slotted fuse plate in California to date.

However, if required in the future, this preliminary study has shown that with some further study, including dynamic testing, a more reliable fuse plate utilizing button welds can be developed for use in breakaway steel posts for highway signs.

VII. REFERENCE

1. "Button Welding" by Byron C. Motl, Machine Design, November 5, 1964, p. 150-155.

MACROPHOTOGRAPHIC ANALYSIS

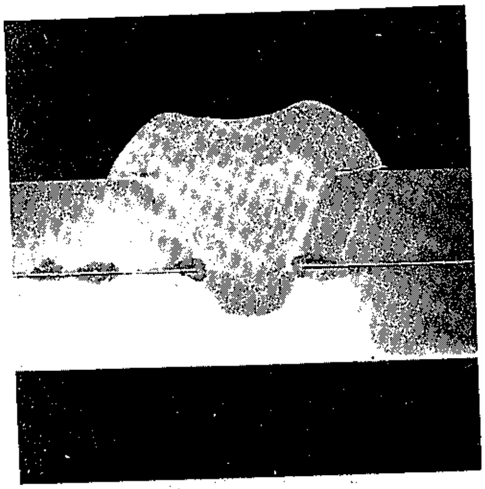
APPENDIX A

TABLE 1

MACROPHOTOGRAPH INTERPRETATION

TEST GROUP NO. 1

Test Specimen No.	Notable Features
1 2 3	Minimum penetration, large weld nugget, button head not wetting, excessive button weld head, round penetration profile.
4	Loss of penetration.
5	No button weld penetration or fusion.
6	No button weld penetration or fusion.
7	Reestablished penetration, minimum button head wetting, large weld nugget.
8	Good penetration, uniform profile, good button head wetting.
9	Good penetration, uniform profile, large area in shear.
10	Less penetration, good fusion, good wetting.
11	Penetration is lessening, good wetting.
12	Loss of penetration
13	Reestablished minimum penetration
14	Premature cycle termination.
15	Small weld nugget, minimum penetration, good wetting, round penetration profile.
1A & 2A	Varying penetration, good wetting, loss of nugget head.
3A & 4A	Substantially differing penetration, flush button head, attractive spiked fusion profile, good wetting.
5A & 6A	Consistent profile, minimum button head, good wetting.
7A & 8A	Fusion area increasing, button head forming, good wetting, good spiked profile.



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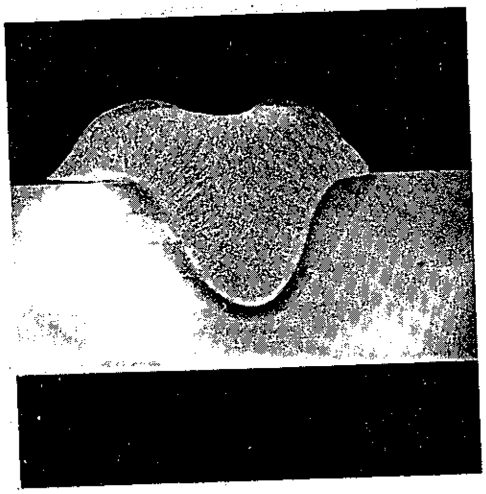

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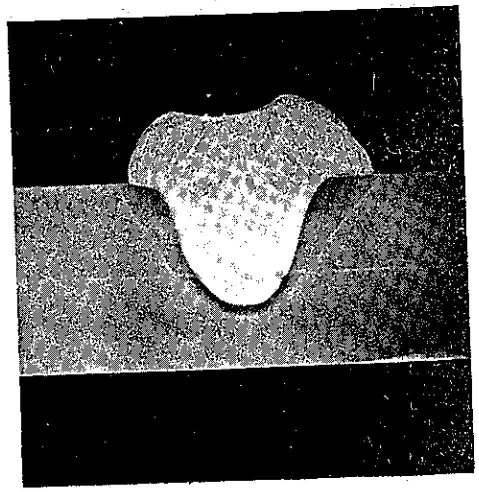

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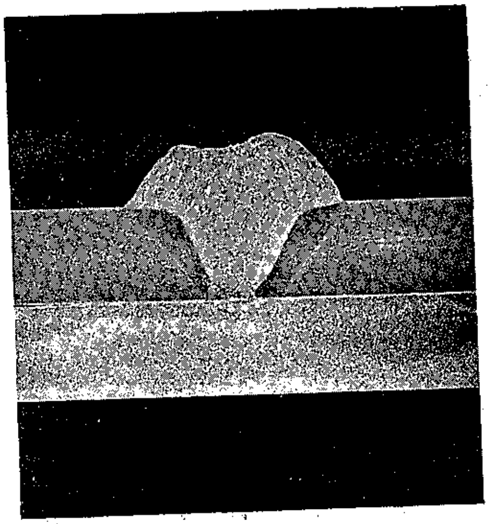

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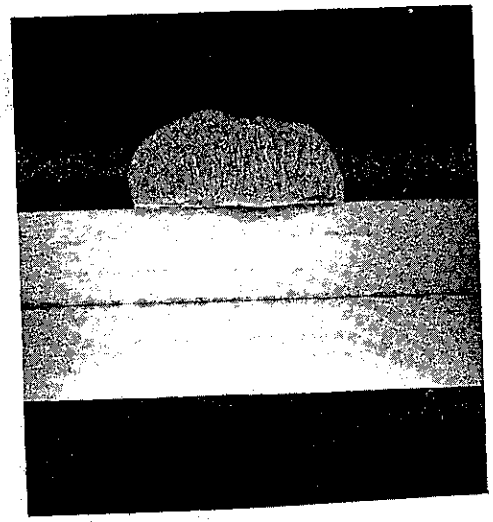

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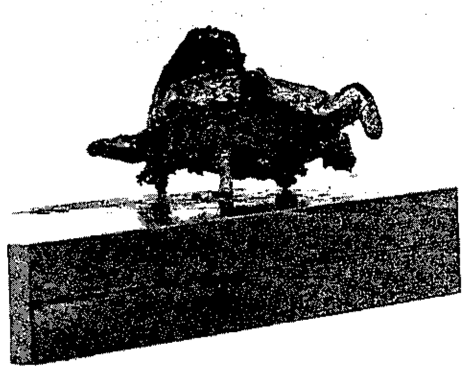

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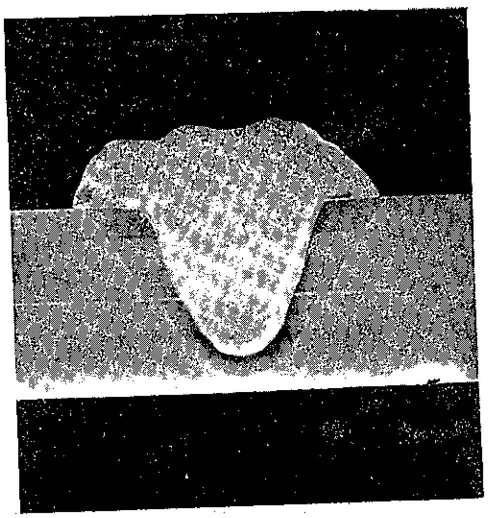

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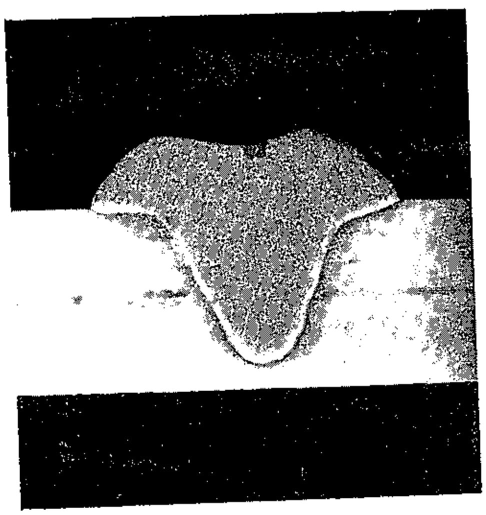

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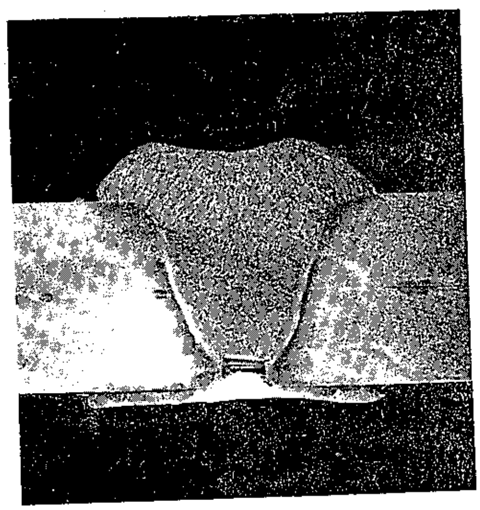
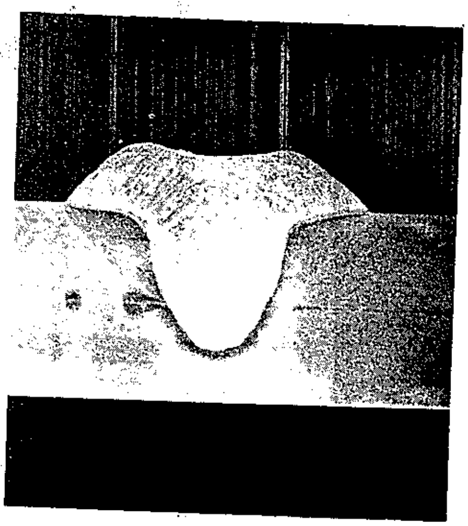


MACROPHOTOGRAPH #9

Appendix A



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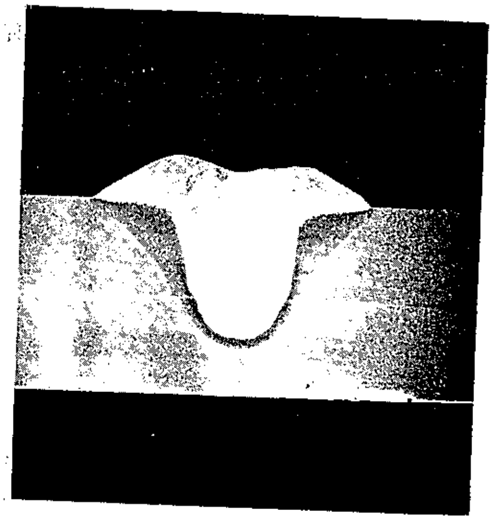

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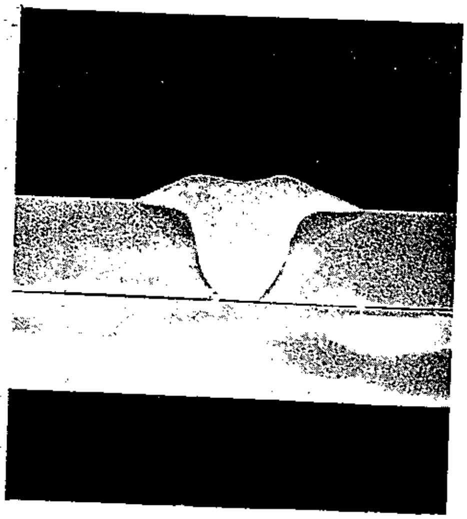

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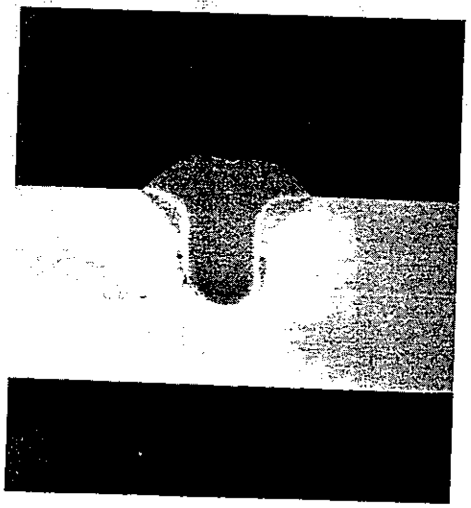

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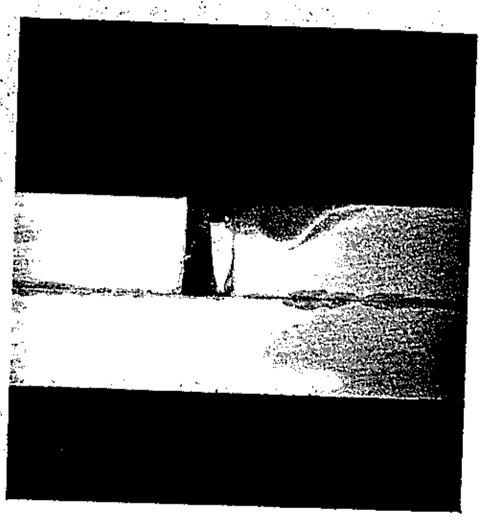

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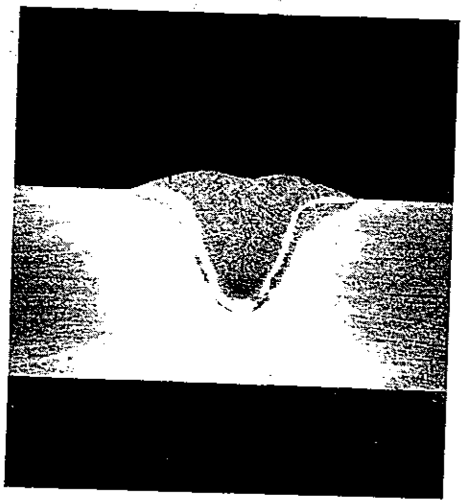

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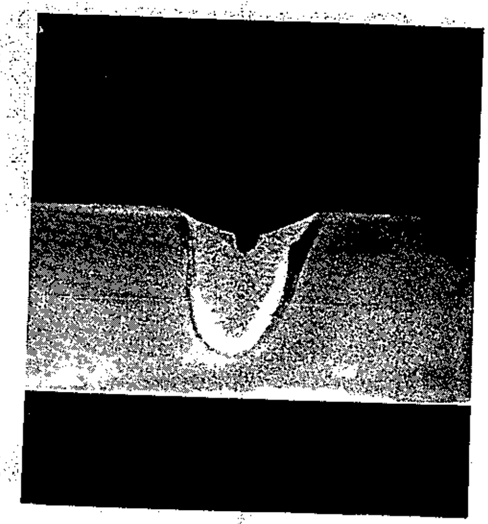

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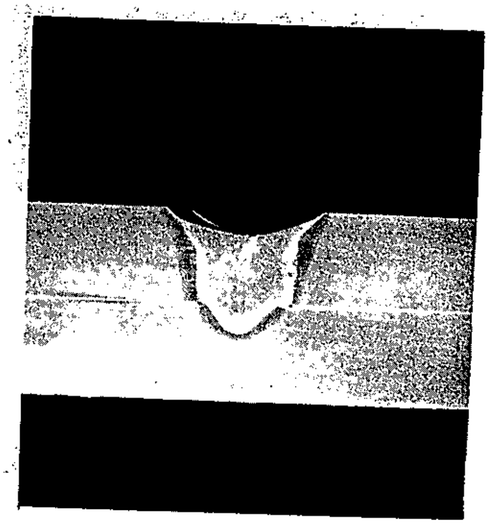

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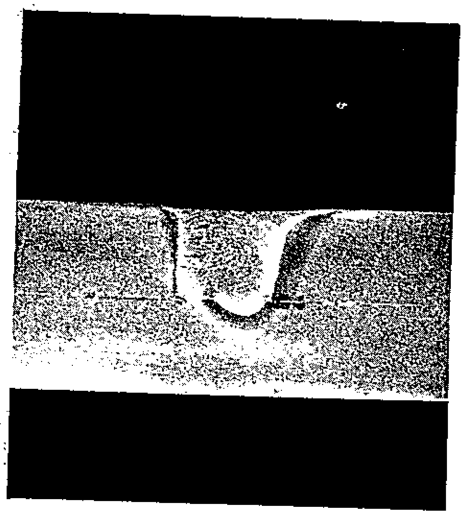

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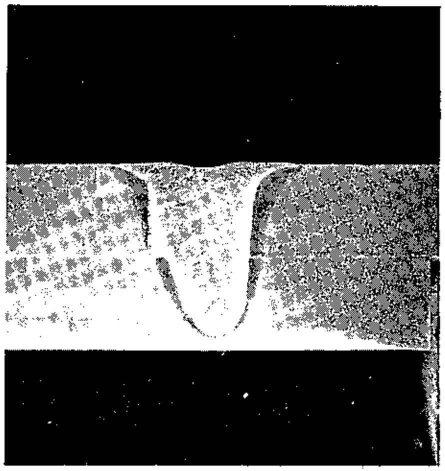

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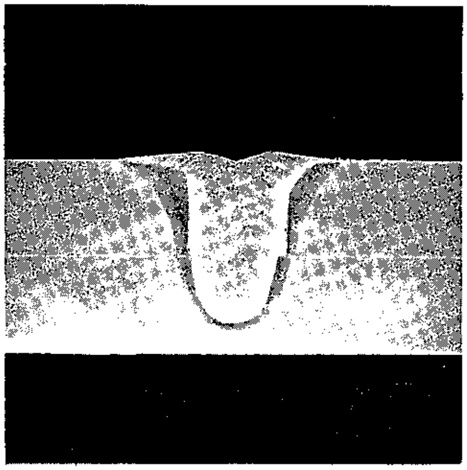

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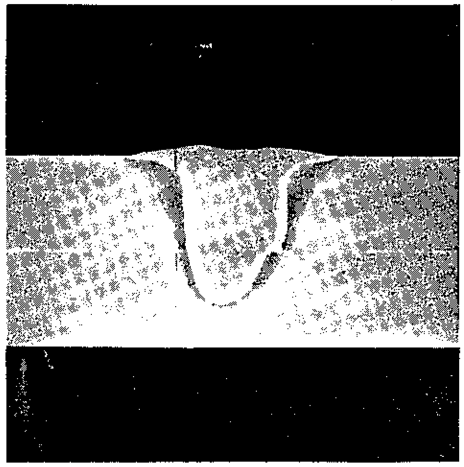

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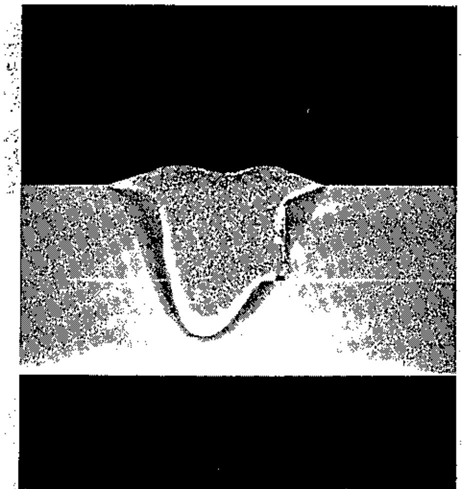

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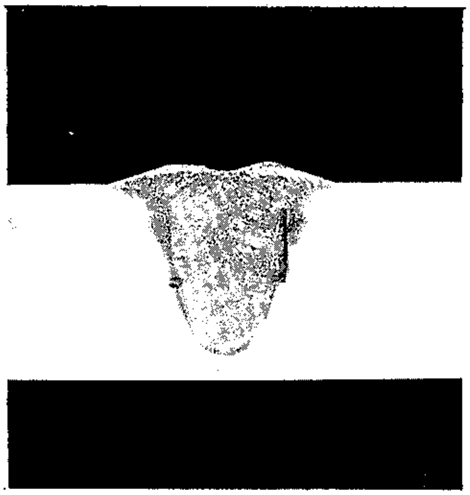

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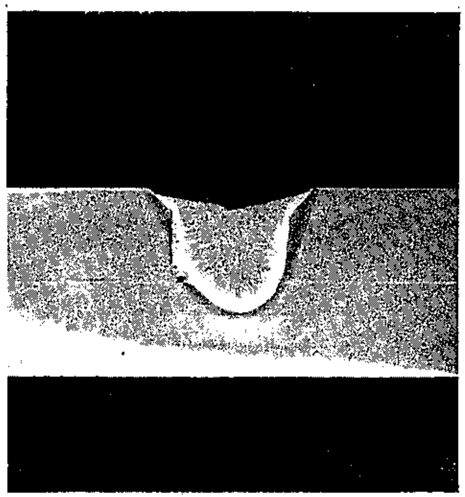

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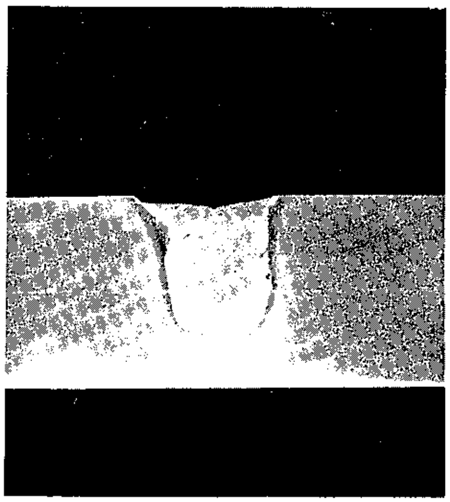

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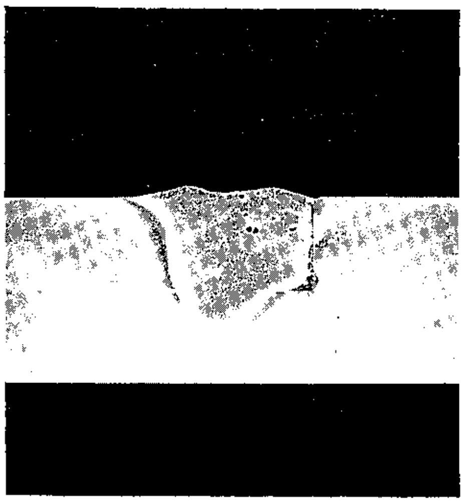

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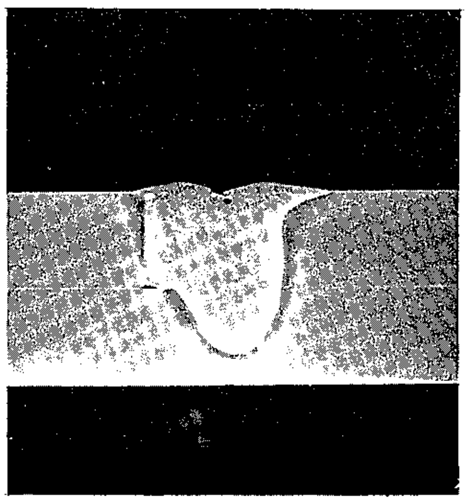

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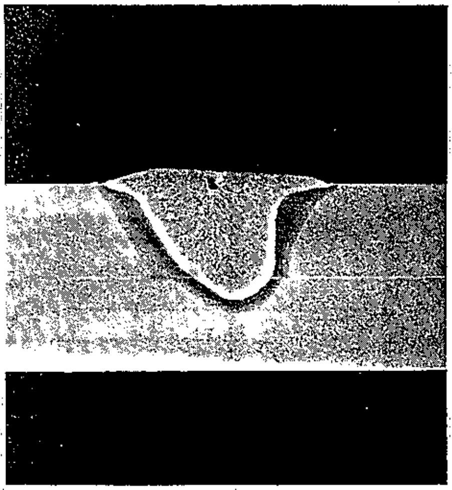
Appendix A



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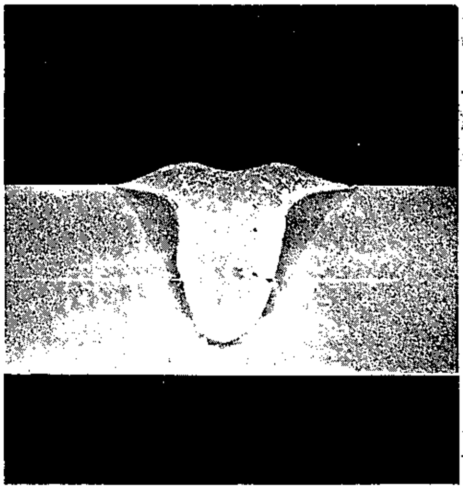

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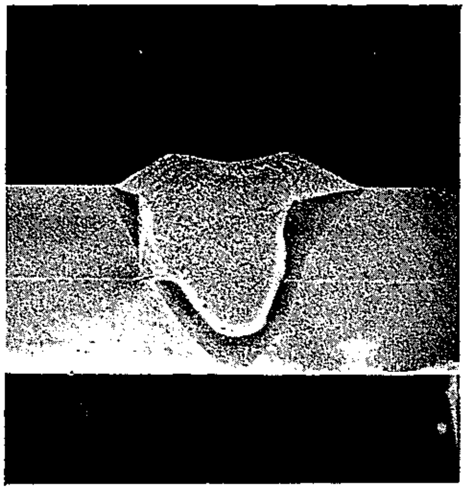

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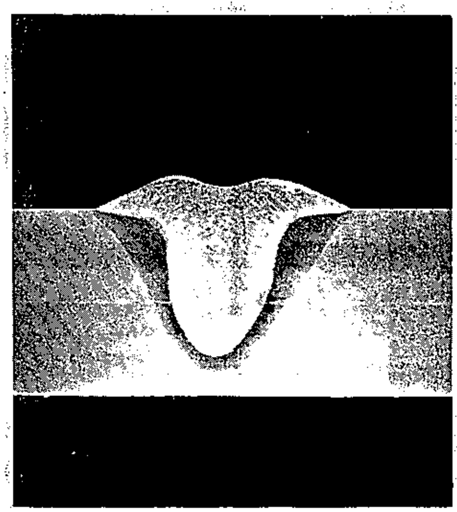

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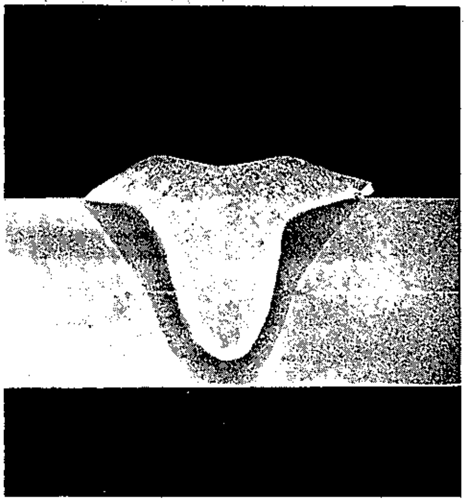

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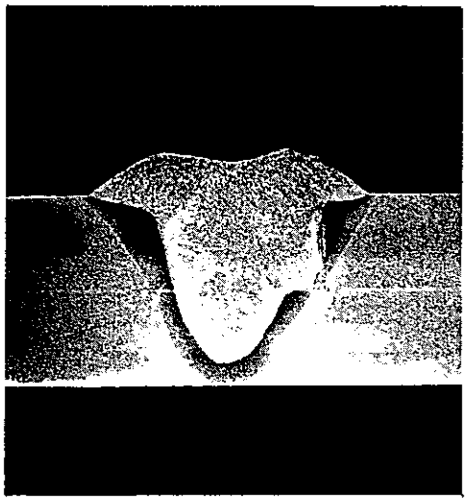

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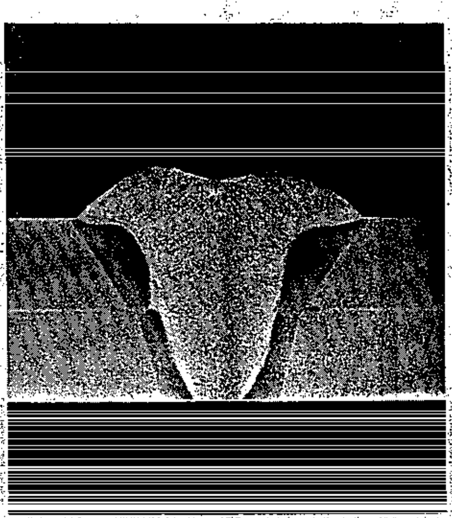

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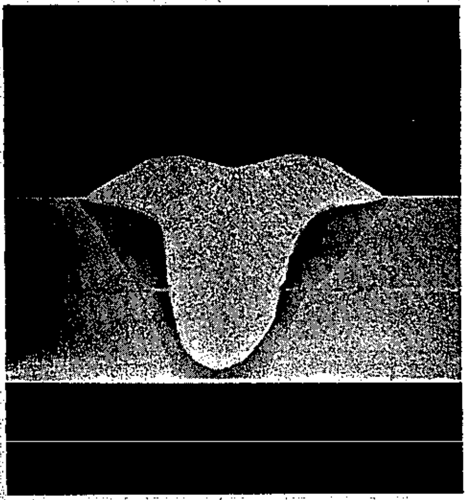


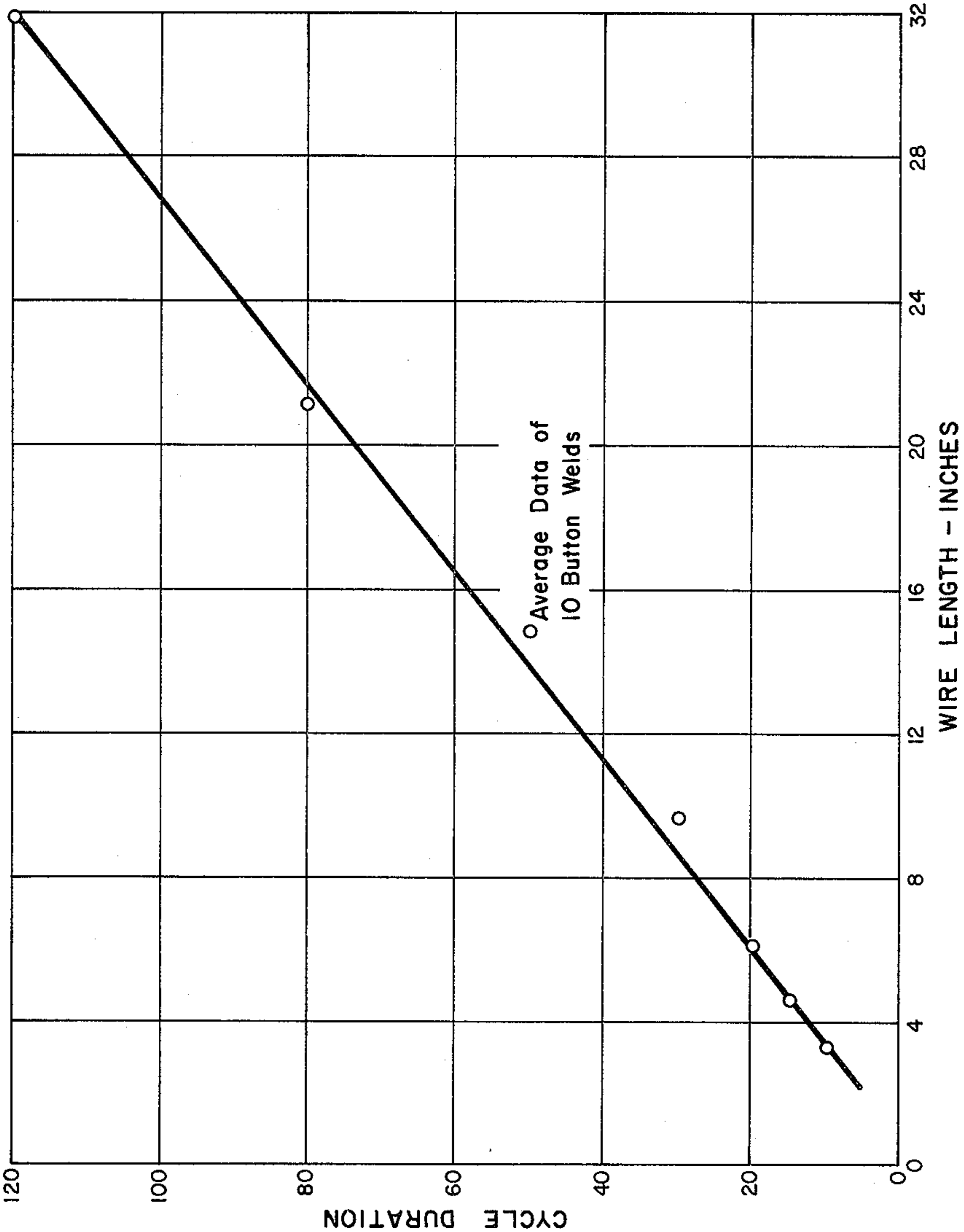
MACROPHOTOGRAPH #48B

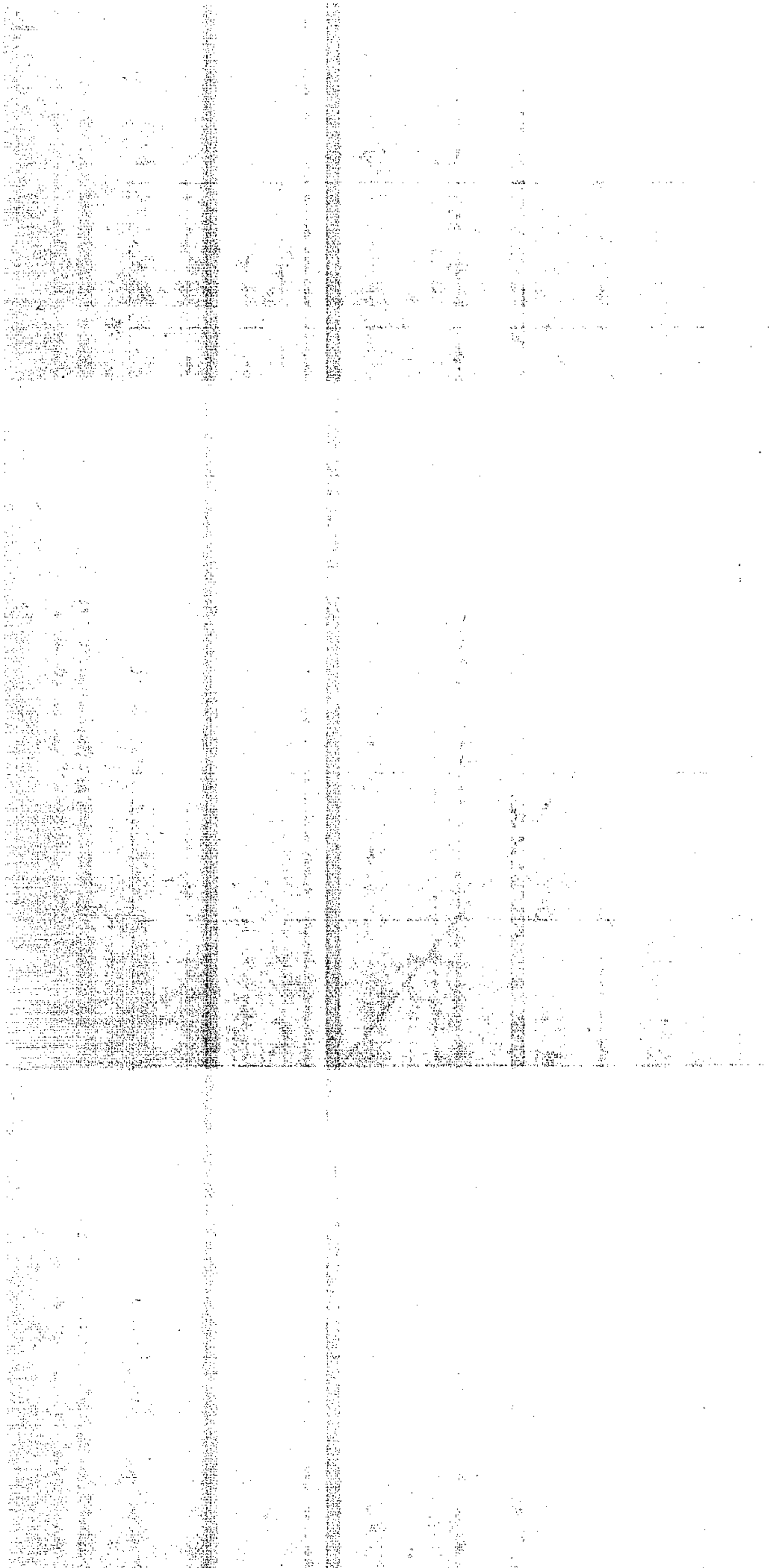
CYCLE DURATION CONTROL CALIBRATION

APPENDIX B

WELDING MACHINE CALIBRATION

LINDE SIGMATIC CONTROL @ 600 AMPERES, 38 VOLTS





BUTTON WELDING DATA

APPENDIX C

TABLE II

TEST GROUP NO. 1

BUTTON NO.	SLOPE %	INDUCTANCE %	CYCLE DURATION	WIRE AMOUNT	AMPERE	VOLTAGE	WIRE SIZE	PILOT HOLE	PLATE THICKNESS	GAS FLOW RATE
1	F @ 85	Low @ 40	100		580	34	1/16	1/8	1/4 to 1/4	40
2	"	"	80		580	34	1/16	1/8	1/4 to 1/4	40
3	"	"	60		600	35	1/16	1/8	1/4 to 1/4	40
4	"	"	40		600	34	1/16	1/8	1/4 to 1/4	40
5	S @ 85	"	100		610	34	1/16	1/8	1/4 to 1/4	40
6	F @ 85	High @ 40	100		400	25	1/16	1/8	1/4 to 1/4	40
7	"	Low @ 10	100		600	35	1/16	1/8	1/4 to 1/4	40
8	F @ 10	"	100		610	38	1/16	1/8	1/4 to 1/4	40
9	"	"	80		580	39	1/16	1/8	1/4 to 1/4	40
10	"	"	60		580	40	1/16	1/8	1/4 to 1/4	40
11	"	"	40		580	40	1/16	1/8	1/4 to 1/4	40
12	"	"	20		580	38	1/16	1/8	1/4 to 1/4	40
13	"	"	15		580	38	1/16	1/8	1/4 to 1/4	40
14	"	"	10		Low	Low	1/16	1/8	1/4 to 1/4	40
15	"	"	10		580	38	1/16	1/8	1/4 to 1/4	40
1A	"	"	10		Low	Low	1/16	1/4	1/4 to 1/4	40
2A	"	"	10		580	38	1/16	1/4	1/4 to 1/4	40
3A	"	"	15		500	38	1/16	1/4	1/4 to 1/4	40
4A	"	"	15		580	38	1/16	1/4	1/4 to 1/4	40
5A	"	"	17½		500	38	1/16	1/4	1/4 to 1/4	40
6A	"	"	17½		500	38	1/16	1/4	1/4 to 1/4	40
7A	"	"	20		580	38	1/16	1/4	1/4 to 1/4	40
8A	"	"	20		580	38	1/16	1/4	1/4 to 1/4	40

TABLE III

TEST GROUP NO. 3

BUTTON NO.	SLOPE %	INDUCTANCE %	CYCLE DURATION	WIRE AMOUNT	AMPERE	VOLTAGE	WIRE SIZE	PILOT HOLE	PLATE THICKNESS	GAS FLOW RATE
1B	F @ 10	Low @ 10	10		400	38	1/16	1/4	1/4 to 1/4	40
2B	"	"	"		"	"	"	"	"	"
3B	"	"	"		"	"	"	"	"	"
4B	"	"	"		"	"	"	"	"	"
5B	"	"	"		"	"	"	"	"	"
6B	"	"	"		"	"	"	"	"	"
7B	"	"	"		"	"	"	"	"	"
8B	"	"	"		"	"	"	"	"	"
9B	"	"	15		500	"	"	"	"	"
10B	"	"	"		"	"	"	"	"	"
11B	"	"	"		"	"	"	"	"	"
12B	"	"	"		"	"	"	"	"	"
13B	"	"	"		"	"	"	"	"	"
14B	"	"	"		"	"	"	"	"	"
15B	"	"	"		"	"	"	"	"	"
16B	"	"	"		"	"	"	"	"	"
17B	"	"	20		580	"	"	"	"	"
18B	"	"	"		"	"	"	"	"	"
19B	"	"	"		"	"	"	"	"	"
20B	"	"	"		"	"	"	"	"	"
21B	"	"	"		"	"	"	"	"	"
22B	"	"	"		"	"	"	"	"	"
23B	"	"	"		"	"	"	"	"	"
24B	"	"	"		"	"	"	"	"	"

TABLE III (Cont'd.)

TEST GROUP NO. 3

BUTTON NO.	SLOPE %	INDUCTANCE %	CYCLE DURATION	WIRE AMOUNT	AMPERE	VOLTAGE	WIRE SIZE	PILOT HOLE	PLATE THICKNESS	GAS FLOW RATE
25B	F @ 10	Low @ 10	30		590	38	1/16	1/4	1/4 to 1/4	40
26B	"	"	"		"	"	"	"	"	"
27B	"	"	"		"	"	"	"	"	"
28B	"	"	"		"	"	"	"	"	"
29B	"	"	"		"	"	"	"	"	"
30B	"	"	"		"	"	"	"	"	"
31B	"	"	"		"	"	"	"	"	"
32B	"	"	"		"	"	"	"	"	"
33B	"	"	40		580	"	"	"	"	"
34B	"	"	"		"	"	"	"	"	"
35B	"	"	"		"	"	"	"	"	"
36B	"	"	"		"	"	"	"	"	"
37B	"	"	"		"	"	"	"	"	"
38B	"	"	"		"	"	"	"	"	"
39B	"	"	"		"	"	"	"	"	"
40B	"	"	"		"	"	"	"	"	"
41B	"	"	50		590	"	"	"	"	"
42B	"	"	"		"	"	"	"	"	"
43B	"	"	"		"	"	"	"	"	"
44B	"	"	"		"	"	"	"	"	"
45B	"	"	"		"	"	"	"	"	"
46B	"	"	"		"	"	"	"	"	"
47B	"	"	"		"	"	"	"	"	"
48B	"	"	"		"	"	"	"	"	"

TABLE IV

TEST GROUP NO. 4

SPECIMEN NO.	SLOPE %	INDUCTANCE %	CYCLE DURATION	WIRE AMOUNT	AMPERE	VOLTAGE	WIRE SIZE	PILOT HOLE	PLATE THICKNESS	GAS FLOW RATE
1C	F @ 10	Low @ 10	10		420	38	1/16	1/4	1/4 to 1/4	40
2C	"	"	"		"	"	"	"	"	"
3C	"	"	"		"	"	"	"	"	"
4C	"	"	"		"	"	"	"	"	"
5C	"	"	"		"	"	"	"	"	"
6C	"	"	"		"	"	"	"	"	"
7C	"	"	"		"	"	"	"	"	"
8C	"	"	"		"	"	"	"	"	"
9C	"	"	"		"	"	"	"	"	"
10C	"	"	"		"	"	"	"	"	"
11C	"	"	"		"	"	"	"	"	"

TABLE V

TEST GROUP NO. 5

12C	F @ 10	Low @ 10	20		580	38	1/16	1/4	1/4 to 1/4	40
13C	"	"	"		"	"	"	"	"	"
14C	"	"	"		"	"	"	"	"	"
15C	"	"	"		"	"	"	"	"	"
16C	"	"	"		"	"	"	"	"	"
17C	"	"	"		"	"	"	"	"	"
18C	"	"	"		"	"	"	"	"	"
19C	"	"	"		"	"	"	"	"	"
20C	"	"	"		"	"	"	"	"	"
21C	"	"	"		"	"	"	"	"	"
22C	"	"	"		"	"	"	"	"	"

ULTIMATE STATIC SHEAR STRENGTH DATA

APPENDIX D

TABLE VI

TEST GROUP NO. 2 DATA

TEST SPECIMEN NO.	ULTIMATE STATIC SHEARING STRENGTH
1	7,000 pounds
2	8,230 pounds
3	5,240 pounds
4	3,900 pounds
5	9,950 pounds

Mean = 6,860 pounds

Std. Dev. = 2,140 pounds

Coef. of Variation = 31%

TABLE VII

TEST GROUP NO. 3 DATA

TEST SPECIMEN NO.	ULTIMATE STATIC SHEARING STRENGTH
2B - 3B	3,960 pounds
4B - 5B	3,720 pounds
6B - 7B	3,880 pounds
10B - 11B	4,180 pounds
12B - 13B	4,300 pounds
14B - 15B	4,000 pounds
18B - 19B	4,300 pounds
20B - 21B	4,170 pounds
22B - 23B	4,500 pounds
26B - 27B	5,770 pounds
28B - 29B	5,330 pounds
30B - 31B	5,720 pounds
34B - 35B	5,540 pounds
36B - 37B	5,510 pounds
38B - 39B	4,800 pounds
42B - 43B	5,790 pounds
44B - 45B	5,860 pounds
46B - 47B	6,100 pounds

TABLE VIII

TEST GROUP NO. 4 DATA

TEST SPECIMEN NO.	ULTIMATE STATIC SHEARING STRENGTH
1C	9,240 pounds
2C	9,870 pounds
3C	8,880 pounds
4C	3,850 pounds
5C	4,300 pounds
6C	8,150 pounds
7C	6,850 pounds
8C	9,250 pounds
9C	8,010 pounds
10C	8,480 pounds

Mean = 7,690 pounds

Std. Dev. = 1,970 pounds

Coef. of Variation = 26%

TABLE IX

TEST GROUP NO. 5

TEST SPECIMEN NO.	ULTIMATE STATIC SHEARING STRENGTH
12C	11,500 pounds
13C	10,750 pounds
14C	10,620 pounds
15C	9,900 pounds
16C	11,620 pounds
17C	12,200 pounds
18C	12,000 pounds
19C	11,400 pounds
20C	10,100 pounds
21C	10,870 pounds

Mean = 11,100 pounds

Std. Dev. = 733 pounds

Coef. of Variation = 6.6%